Electricity-Generating Device Retrofitted for Spin Bikes with Wall Outlet Plug Connected to Gym's Grid

ECE 445 Project Proposal

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1 Introduction

1.1 Problem

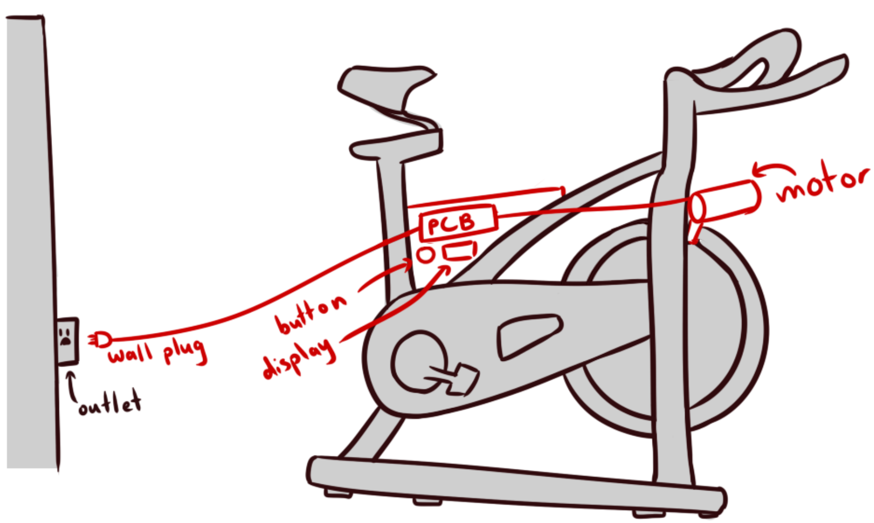
Something we take for granted everyday is energy. There is energy consumed constantly in malls, offices, schools, vehicles, gyms, and more. The special thing about gyms is that there is almost always someone using exercise machines like the elliptical, treadmill or bike. Now what if, along with losing those extra pounds, you can also generate some electricity using these machines? Our device is a straightforward and cheap alternative for gyms to have retrofitted spin bikes that generate electricity, and for the gym to save money by connecting the electricity-generating exercise bike to the gym's grid by simply plugging the device into the wall outlet.

1.2 Solution

We are retrofitting a spin bike with an electricity-generating device that can be plugged into the wall outlet, which will be the path to send the generated electricity back to the gym's grid to be used. The amount of electricity generated will also be monitored and displayed with the device, and can be reset with a button press.

The wheel of the spin bike will be attached to a motor with a DC output, and then the power will be converted to AC. This signal will be synchronized with the grid using the microcontroller, and the power is ultimately sent to the gym's grid through the wall outlet. Information from a current sensor will be used to calculate the total power generated from the bike after the last reset button press, and this calculation will be done through the microcontroller and will be shown on the display.

1.3 Physical Design



1.4 High-level Requirements List

1.4.1 Electricity Generating Efficiency

The average biker can generate an average of 200-300W for about an hour from an exercise bike [1]. In addition, the power consumption of a TV is usually 80-400W [2]. Based on these numbers, we want to verify that our efficiency is good enough by having one of our group members use the spin bike for 1 minute and generate at least 1.33Wh in that 1 minute and maintain a power output of at least 80W, which can power a low power TV. This success can be verified with our metering.

1.4.2 Grid Synchronization

The final bike output signal will be synchronized with the grid. That is, the frequency, voltage and phase of the signal must line up with the grid. The grid will be modeled by a test circuit, and the bike output signal will be measured to see if the two signals match.

Our bike would be considered a distributed energy resource (DER). IEEE 1547-2018 [3] is the IEEE standard for interconnections between DERs and the grid. The table below from the IEEE 1547-2018 shows the maximum difference in frequency, voltage and phase angle between our output and the grid. Our system would be rated less than 500 kVA, so the first row of the table below provides the corresponding requirements.

Additionally, our system will be able to withstand voltage and current surges by maintaining the output voltage, as well as achieve a power factor of at least 0.9.

Table 5—Synchronization parameter limits for synchronous interconnection to an EPS, or an energized Local EPS to an energized Area EPS

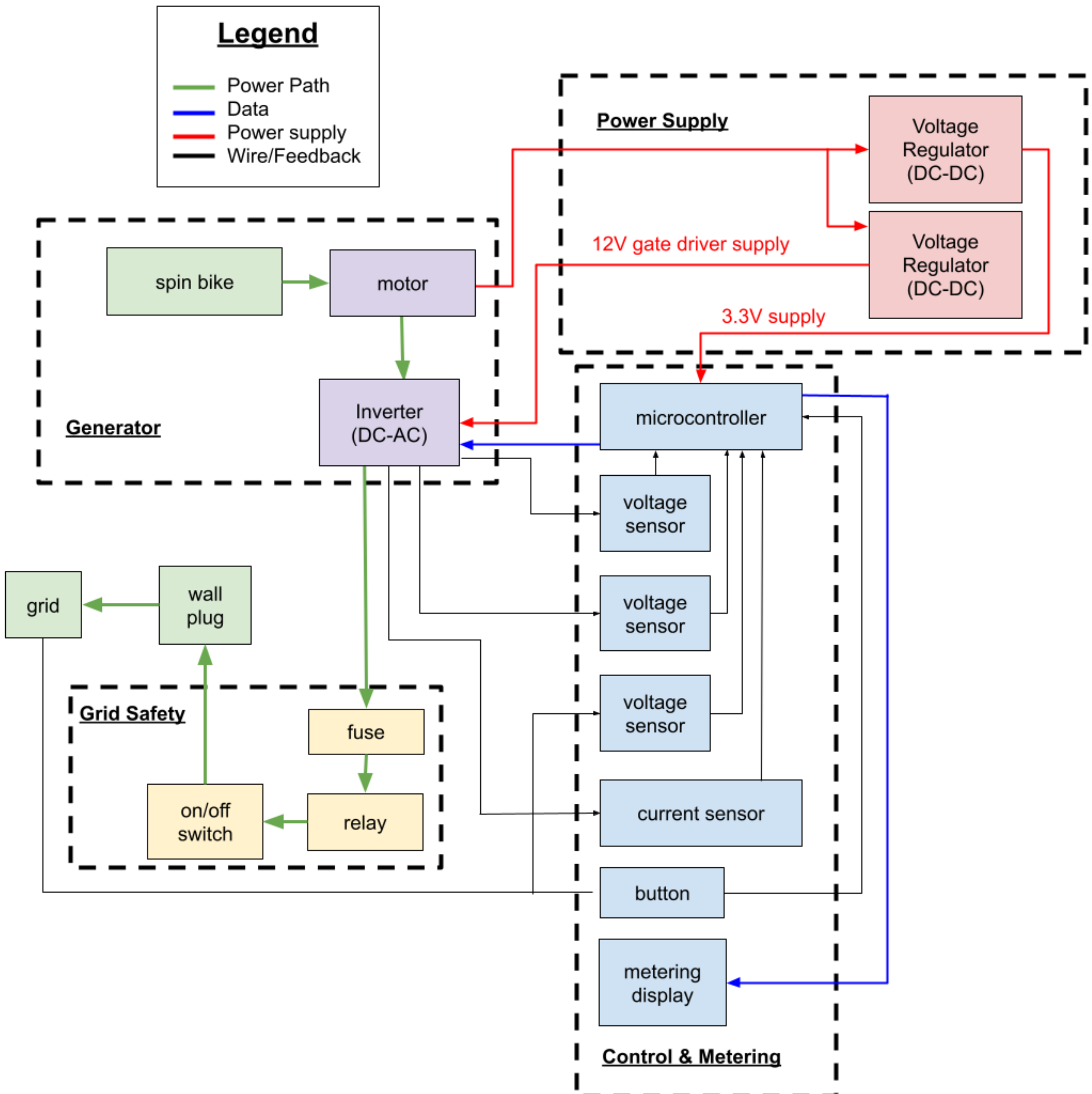
Aggregate rating of DER units (kVA)	Frequency difference (Δf, Hz)	Voltage difference (ΔV, %)	Phase angle difference ($\Delta \Phi$, °)
0–500	0.3	10	20
> 500–1 500	0.2	5	15
> 1 500	0.1	3	10

1.4.3 Metering success

Based on our electricity-generating success scenario in section 1.4.1 Electricity Generating Efficiency, the display will read at least 1.33Wh after our group member bikes for 1 minute. In addition, the display will show the current power output during that 1 minute. The meter will update every second as our group member is biking, and it will immediately reset to 0 when the button is pressed.

2 Design

2.1 Block Diagram



2.2 Subsystem Overview:

2.2.1 External Interface Devices

Grid (Simulated)

The bike generator will output power to the gym's grid. For testing, the bike will not actually connect to the power grid. Instead, the "grid" signal will be generated using a function generator, a sinusoidal signal of 60 Hz. Our device will be attached to this signal to sync up with it.

Requirement 1: Able to generate a sinusoidal signal at 60 Hz within ± 10 mHz.

Wall plug

This will be the plug that connects the grid-synchronized power generated by the bike to the grid using the wall outlet.

Requirement 1: Must be able to safely run up to 5 A.

2.2.2 Generator

Spin bike

The spin exercise bike will be the source for generating electricity. A mechanical device will couple the flywheel of the bike to a motor.

Requirement 1: Must have an open flywheel that the motor can attach to.

Motor

There will be a 200-300W motor attached to the wheel of the bike. The motor will start up once the person starts pedaling the bike. The motor is made of a spinning magnet within a coil of wire, and as the magnet spins, the electricity flows through the coil.

Requirement 1: Must be able to generate up to 200 W of power.

Requirement 2: Must be able to generate a voltage ranging from 0 to 24 V when the bike is pedaled.

Inverter

There will be two major parts of the inverter system.

The first part is the DC-DC converter. This is to help stabilize the voltage supply. It passes a current through a "switching element" such as a diode. Then it turns the signal into a square wave and passes it through another wave to change back into the DC signal. This will increase the voltage output of the motor to the nominal voltage of the grid. The DC-DC converter is necessary to boost the voltage up to 170V, the peak value of the final sinusoidal voltage output. [5]

The second part is an inverter. The DC voltage generated by the motor needs to be converted to AC since the grid is an AC system. Using an inverter, it is relatively easy to control the frequency of the output voltage, which is important for synchronization. Therefore, an inverter is necessary to convert our DC current to AC in order to connect to the grid.

Requirement 1: DC-DC converter must be able to output 200 W at 170 V ±10%.

Requirement 2: Inverter must be able to output 200 W at 120 Vrms ±10% with a power factor of 0.9 or greater.

Requirement 3: Output voltage frequency must be able to synchronize to an external sinusoidal signal's frequency within ±10% and have no more than a 20° phase angle between the two.

2.2.3 Grid Safety

Fuse

The fuse will supply feedback protection in case a dangerous amount of power is received from the grid, which could be caused due to a fault in a component.

Requirement 1: If the current meets or exceeds the maximum current that the fuse can take, the fuse must disconnect the circuit within 2 seconds.

Relay

The relay will be connected to the grid as an additional safety measure. If there is no power being generated, this will disconnect the device from the grid.

Requirement 1: Must be able to disconnect the generator subsystem from the grid within 2 seconds of the bike not generating electricity.

On/Off Switch

This will be used to manually disconnect the device from the grid. We want to be able to disconnect the circuit for safety reasons. If someone is working on the grid, we do not want to be outputting power, potentially endangering the worker.

Requirement 1: When the switch is turned off, the device must disconnect within 1 second.

2.2.4 Control & Sensors

Microcontroller

The microcontroller will be the ATmega328. The microcontroller will include the PLL (phase locked loop) algorithm for grid synchronization. See other subsystem parts in this section (2.2.4 Controls & Sensors) for more information on what the microcontroller is being used to do.

Requirement 1: Power consumption must be less than 500 mW.
Requirement 2: When someone starts using the bike and the microcontroller receives sufficient power to operate, the microcontroller must achieve the requirements listed in section 1.4.2 Grid Synchronization in under 10 seconds.

Voltage Sensors

Three voltage sensors will be needed. Two voltage sensors will be used to sense the output voltages of the inverter and dc-dc converter for voltage control. The third voltage sensor will be needed for synchronization to the grid. The grid's voltage is input into the PLL algorithm which will sync our output voltage to the grid.
Requirement 1: Must be able to sense voltage with an accuracy of ±1%.

Current Sensor

The current sensor's information will be used to measure the amount of electricity generated. It will measure the AC current information being sent to the grid, and this sensor will be connected to an analog input pin on the microcontroller.
Requirement 1: Display measurements must match a reference ammeter measurement by ±2%.

Button

When this button is pressed, the microcontroller instantaneously resets the total power generated data to 0, which can be viewed with the display. The button will be connected to an external interrupt pin on the microcontroller.
Requirement 1: Reset the total power displayed to 0 in less than 1 second.

Display

The display will show how much energy has been generated since the reset button was last pressed, and will also show how much power is being output from the bike. Both values are updated every second. An LCD display will be used since it is less expensive than an LED display [6]. The display will show the power generated as whole numbers,
Requirement 1: The energy generated must be displayed to two decimal points. The units must be in Wh (Watt-hours).
Requirement 2: The power generated must be displayed to two decimal points.

2.2.5 Power Supply

Voltage Regulators

The voltage regulators change the DC motor output to the appropriate voltage levels needed to provide the power supply for the inverter and the microcontroller.

12V Gate Driver Supply: The generator auxiliary circuit supply will be needed to drive the MOSFETs in power converters. Depending on the MOSFET in our design, the supply will need to be around 12V.
Requirement 1: Must regulate a voltage to 12 ±2V.
Requirement 2: Must be able to meet Requirement 1 with a wide range of input voltages from 5 to 24 V.

3.3V Supply: The 3.3V supply will be used to power the microcontroller. The microcontroller has an operating voltage of 1.8 - 5.5V [7].
Requirement 1: Must regulate a voltage of 3.3 ±1V.
Requirement 2: Must be able to meet Requirement 1 with a wide range of input voltages from 5 to 24 V.

2.3 Tolerance Analysis

Synchronization with grid:

The main issue we will run into for this project is being able to check if the electricity generated by the bike will be able to safely synchronize into a gym's distribution system. Due to safety concerns, instead of directly connecting to the grid, we need some kind of way to test our synchronization. We will need to create a mock setup to simulate the grid. Some problems could arise since we need to figure out an algorithm for the simulation which may or may not accurately reflect the behavior of the real grid.

3 Ethics and Safety

Section 1.1 of IEEE code of conduct states that we must "hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, to protect the privacy of others, and to disclose promptly factors that might endanger the public or the environment." [8] The rule applies to the project since it will be dealing with high voltages and synchronization with the grid.

One of the dangers to this project is the high voltage and power. In order to account for this, there will be several safety features in case of power surges, overheating, and loss of voltage regulation. The main safety features will be the fuse and relay. If there is too much power received from the grid, the fuse will break the circuit. The other safety feature will be the relay. If something goes wrong with the connection to the grid, the relay will open the circuit. In addition, there will be an on/off switch to manually cut the device's connection with the grid.

The other issue we may run into is when we are synchronizing to the grid. If our frequency does not match, it might damage the gym's grid. This would affect the welfare of the people in the gym. Since the power we are generating is not large enough to do significant disruption to the grid, this issue will most likely not be our concern. If any issues were to arise, we have multiple safety measures to turn off our power connection.

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